NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

REPORT No. 340

FULL SCALE WIND TUNNEL TESTS ON SEVERAL METAL PROPELLERS HAVING DIFFERENT BLADE FORMS

By FRED E. WEICK

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AERONAUTICAL SYMBOLS

1. FUNDAMENTAL AND DERIVED UNITS

	Symbol	Metric		English	
		Unit	Symbol	Unit	Symbol
Length	l	meter	m	foot (or mile)	ft. (or mi.)
Time	t	second	s	second (or hour)	sec. (or hr.)
Force	F	weight of one kilogram	kg	weight of one pound	lb.
Power	P	kg/m/s		horsepower	hp
Speed		{km/hr	k. p. h.	mi./hr.	m. p. h.
		{m/s	m. p. s.	ft./sec.	f. p. s.

2. GENERAL SYMBOLS, ETC.

W, Weight, $=mg$

g, Standard acceleration of gravity $=9.80665$ m/s^2 $=32.1740$ ft./sec.^{2}

m, Mass, $=\frac{W}{g}$

ρ, Density (mass per unit volume).

Standard density of dry air, 0.12497 (kg-m^{-4} s^2) at 15° C and 760 mm $=0.002378$ (lb.-ft.$^{-4}$ sec.^{2}).

Specific weight of "standard" air, 1.2255 kg/m^3 $=0.07651$ lb./ft.^{3}

mk^2, Moment of inertia (indicate axis of the radius of gyration, k, by proper subscript).

S, Area.

S_w, Wing area, etc.

G, Gap.

b, Span.

c, Chord length.

b/c, Aspect ratio.

f, Distance from C. G. to elevator hinge.

μ, Coefficient of viscosity.

3. AERODYNAMICAL SYMBOLS

V, True air speed.

q, Dynamic (or impact) pressure $=\frac{1}{2}\rho V^2$

L, Lift, absolute coefficient $C_L=\frac{L}{qS}$

D, Drag, absolute coefficient $C_D=\frac{D}{qS}$

C, Cross-wind force, absolute coefficient $C_C=\frac{C}{qS}$

R, Resultant force. (Note that these coefficients are twice as large as the old coefficients L_C, D_C.)

i_w, Angle of setting of wings (relative to thrust line).

i_t, Angle of stabilizer setting with reference to thrust line.

γ, Dihedral angle.

$\rho\frac{Vl}{\mu}$, Reynolds Number, where l is a linear dimension.

e. g., for a model airfoil 3 in. chord, 100 mi./hr. normal pressure, 0° C: 255,000 and at 15° C., 230,000;

or for a model of 10 cm chord 40 m/s, corresponding numbers are 299,000 and 270,000.

C_p, Center of pressure coefficient (ratio of distance of C. P. from leading edge to chord length).

β, Angle of stabilizer setting with reference to lower wing, $=(i_t-i_w)$.

α, Angle of attack.

ϵ, Angle of downwash.

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By FRED E. WEICK
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SUMMARY

This report gives the full-scale aerodynamic characteristics of five different aluminum alloy propellers having four different blade forms. They were tested on an open cockpit fuselage with a radial air-cooled engine having conventional cowling, in the Twenty-Foot Propeller Research Tunnel of the National Advisory Committee for Aeronautics, at Langley Field, Va. The results show that (1) the differences in propulsive efficiency due to the differences in blade form were small; (2) the form with the thinnest airfoil sections had the highest efficiency; (3) it is advantageous as regards propulsive efficiency for a propeller operating in front of a body, such as a radial engine, to have its pitch reduced toward the hub.

INTRODUCTION

Incidental to various investigations in the Propeller Research Tunnel of the National Advisory Committee for Aeronautics, Langley Field, Va., aerodynamic tests have been made on five miscellaneous aluminum alloy propellers, four of which had somewhat different blade forms. All of the propellers had approximately the same pitch, making the results more or less directly comparable, and the data have been collected in this report to show the relative aerodynamic qualities of the various blade forms. The tests were all run at propeller revolutions low enough to be below the effects of high tip speeds. (Reference 1.)

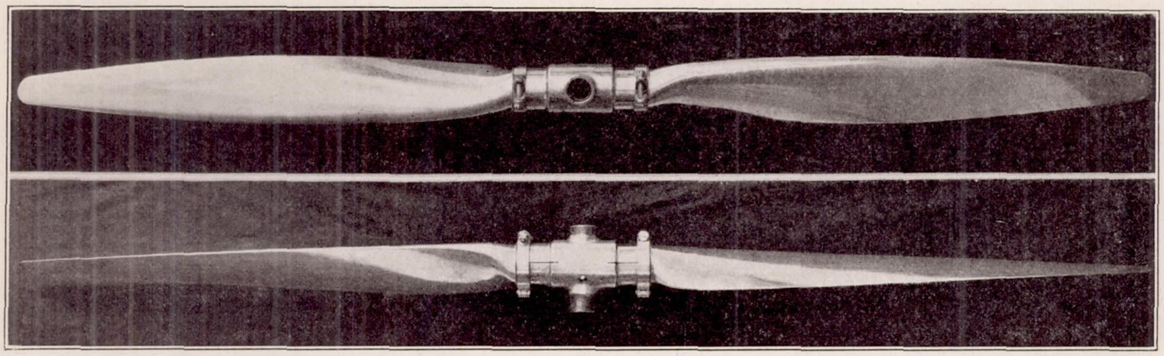


Figure 1.—Metal propeller No. 4412

METHODS AND APPARATUS

The propellers were all made of solid forged aluminum alloy, four of them being of the detachable blade type with a split steel hub, and one of the 1-piece Reed–R type. The detachable blade propellers all bear certain relations to each other, for they represent a progressive development. A photograph of one of them (No. 4412) is given in Figure 1, and a view of the Reed–R type propeller is shown in Figure 2. Curves showing the relative blade forms are given in Figure 3. The propellers may be listed as follows:

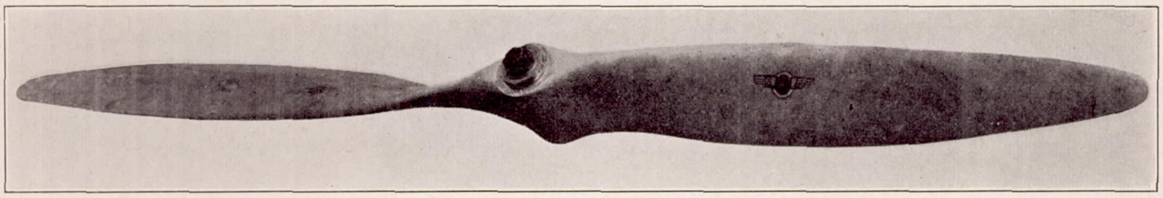


Figure 2.—Reed–R type propeller

- Navy Drawing No. 3790: 8 feet 11 inches diameter; narrow tip; direct drive.
- Navy Drawing No. 3603: 10 feet 5 inches diameter; wide tip; geared.
- Navy Drawing No. 4102: 10 feet 5 inches diameter; wide tip; thick blade; geared.

Navy Drawing No. 4412: 8 feet 11 inches diameter; wide tip; thick blade; direct drive.

No. M–1826, Curtiss Drawing X–33525–69: 9 feet diameter; Reed–R type; direct drive.

The same steel hub was used for all of the detachable blade propellers, and this hub had been made 1 inch shorter than standard in order to save weight, so that, which point it gradually tapers off to the same thickness as No. 3603 at the tip. No. 4412 is geometrically similar to No. 4102 in every respect, except that they both fit the same hub, which is unimportant aerodynamically.

All of the detachable blade propellers had standard airfoil sections based on the R. A. F. 6, as shown in

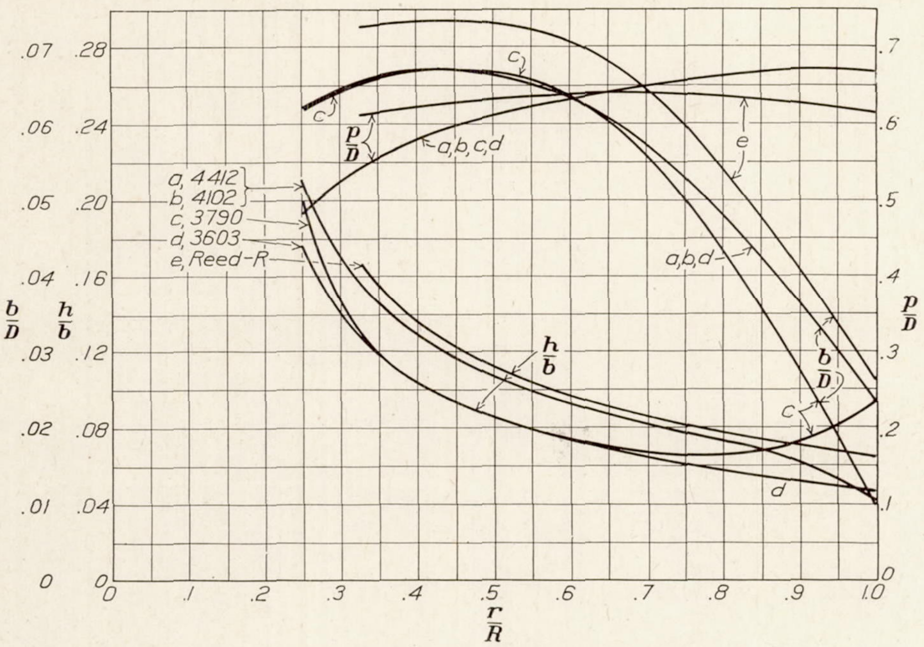
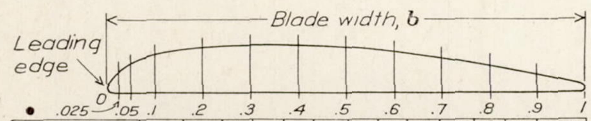


FIGURE 3.—Propeller blade form curves

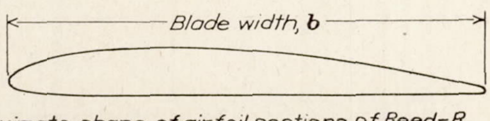
although the designed propeller diameters were 9 feet and 10 feet 6 inches, they were actually 8 feet 11 inches and 10 feet 5 inches as tested. The change in the blade form ratios due to the slightly smaller diameter is scarcely noticeable in the curves of Figure 3.

Propeller No. 3790 was the first of the detachable blade designs of this group. Propeller No. 3603 is



STATION	R.L.E.	.025	.05	.1	.2	.3	.4	.5	.6	.7	.8	.9	R.T.E.
ORD./MAX. ORD.	.10	.41	.59	.79	.95	1.00	.99	.95	.87	.74	.56	.35	.077

Standard propeller section based on R.A.F–6



Approximate shape of air foil sections of Reed–R type propeller. Modified Clark–Y

FIGURE 4

geometrically similar to No. 3790 in pitch distribution and blade thickness, but from about one-half the radius to the tip the blade is wider and the section thickness ratio $\frac{h}{b}$ is lower. Propeller No. 4102 is the same as No. 3603, except that the thickness is 25 per cent greater up to 80 per cent of the tip radius, from Figure 4. The Reed-R type propeller, however, had sections based on the Clark Y, but somewhat thickened at the trailing edge. An approximate contour of this section is also shown in Figure 4. The plan form of the R type blades was very similar to that of the wide tip detachable blades, but the blade width was a little greater. The section thickness ratios were approximately the same as for propellers Nos. 4412 and 4102.

The mean geometrical pitch of all of the propellers was very nearly the same. All the detachable blade propellers had not only the same average geometrical pitch, but the same distribution of pitch along the radius. The pitch increased from hub to tip, and near the hub it was reduced to a very low value. The pitch of the Reed-R propeller, however, was nearly uniform along the radius.

The 8-foot 11-inch and 9-foot propellers were direct drive, but the 10-foot 5-inch propellers were geared 2 : 1. A direct comparison may, therefore, be made only among the group of three direct-drive propellers by themselves and between the two-geared propellers by themselves. However, since one of the geared propellers was geometrically similar to one of the direct-drive propellers, an indirect comparison may be made among all four blade forms.

The Propeller Research Tunnel is of the open-throat type, with an air stream 20 feet in diameter in which

velocities up to 110 m. p. h. can be obtained. A description of the tunnel and also the balances and other measuring devices is given in Reference 2.

The propellers were tested on an open-cockpit fuselage with a conventionally cowled 9-cylinder 200-horsepower Wright J–5 radial air-cooled engine, as shown in Figure 5. The engine was mounted on a dynamometer inclosed within the fuselage so that the torque could be measured directly. The engine torque as measured included the torque on the cylinders due to the twist of the slip stream. In order to correct for this effect a special test was made in which three J–5 cylinders complete with valve gear were mounted under the front portion of a water-cooled Wright E–2 engine on a VE–7 fuselage in the Propeller Research Tunnel. (Fig. 6.) The cylinders were in the same position relative to the propeller as on a J–5 engine. The middle cylinder only was supported in such a manner that its torque about the engine axis could be measured. The torque on the middle cylinder was then found for various engine and air speeds, and the results have been used to apply a correction, amounting to as much as 3 per cent, to the engine torque and power.

The resultant horizontal force of the propeller-body combination, which may be either a thrust or a drag, was measured on the regular thrust balance. This resultant horizontal force R, may be thought of as being composed of three horizontal components, such that

$$R = T - D - \Delta D$$

where

T = the thrust of the propeller while operating in front of the body (the tension in the propeller shaft).

D = the drag of the airplane alone (without propeller) at the same air velocity and density.

ΔD = the increase in drag of the airplane with propeller, due to the slip stream.

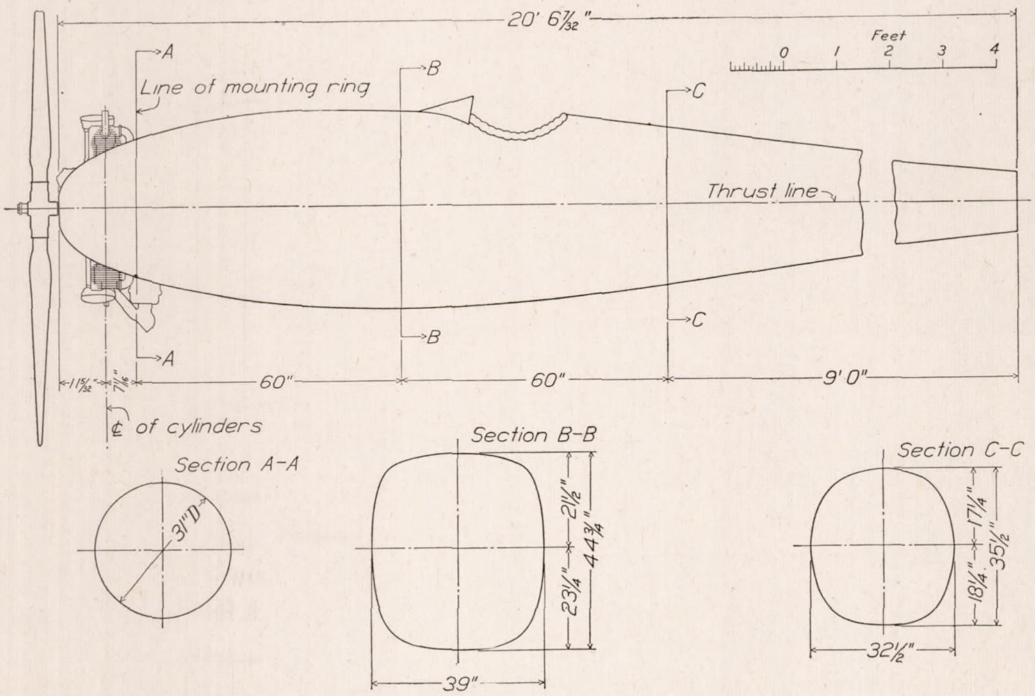


FIGURE 5.—Fuselage and direct drive J–5 engine

Note.—With geared engine, nose was pointed and propeller was 7½ inches farther forward.

In order to obtain the propulsive efficiency, an effective thrust is used which is defined as

$$\text{Effective thrust} = T - \Delta D$$

$$= R + D$$

The propulsive efficiency is then the ratio of the useful power to the input power, or

$$\text{Propulsive efficiency} = \frac{\text{effective thrust} \times \text{velocity of advance}}{\text{input power}}$$

This includes the increase in drag of all parts of the airplane affected by the slip stream, and also the effect of the body interference on the propeller thrust and power.

RESULTS

The observed data points for each of the five propellers tested are given in Figures 7 to 11 and in

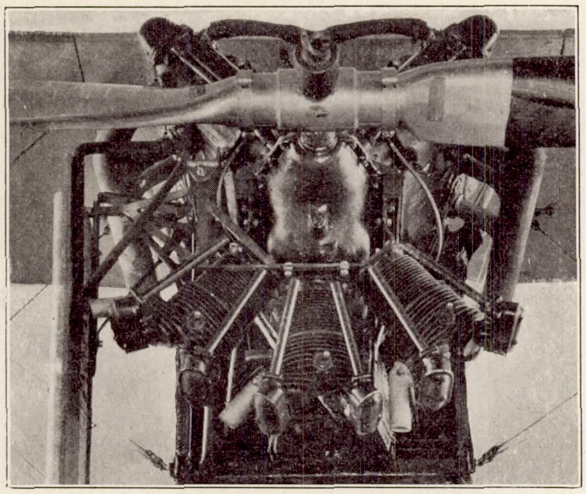


FIGURE 6.—J-5 cylinders mounted on E-2 engine for slip stream torque tests

Table I. They are reduced to the usual coefficients of thrust, power, and propulsive efficiency.

$$C_T=\frac{\text{effective thrust}}{\rho n^2 D^4}$$

$$C_P=\frac{\text{input power}}{\rho n^3 D^5}$$

$$\eta=\frac{\text{effective thrust}\times\text{velocity of advance}}{\text{input power}}$$

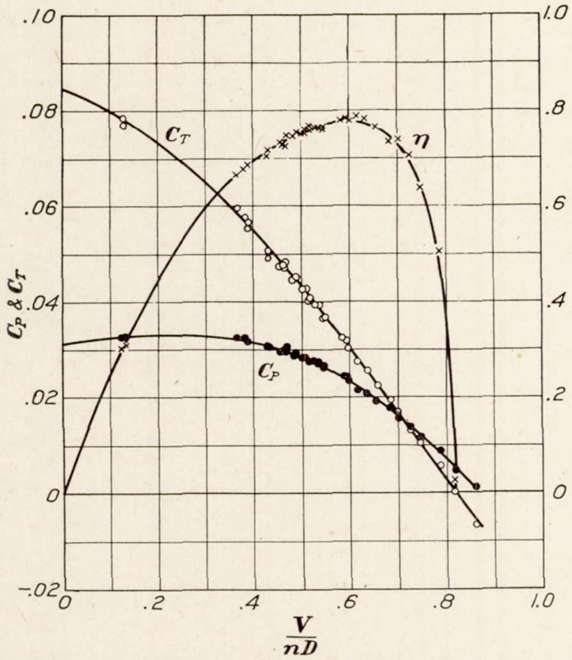


FIGURE 7.—Propeller No. 3790. Diameter 8 feet 11 inches

where D is the propeller diameter and n represents the revolutions per unit time. Since the coefficients are dimensionless, any homogeneous system of units may be used.

In Figure 12 the thrust, power, and efficiency curve of the three direct-drive propellers are compared, and in Figure 13 those of the two-geared propellers. The propellers are grouped similarly in Figures 14 and 15, in which the propulsive efficiencies are plotted against the coefficient

$$C_S=\sqrt[5]{\frac{\rho V^5}{P n^2}}$$

where V is the velocity of advance and P represents the power absorbed by the propeller. Propellers

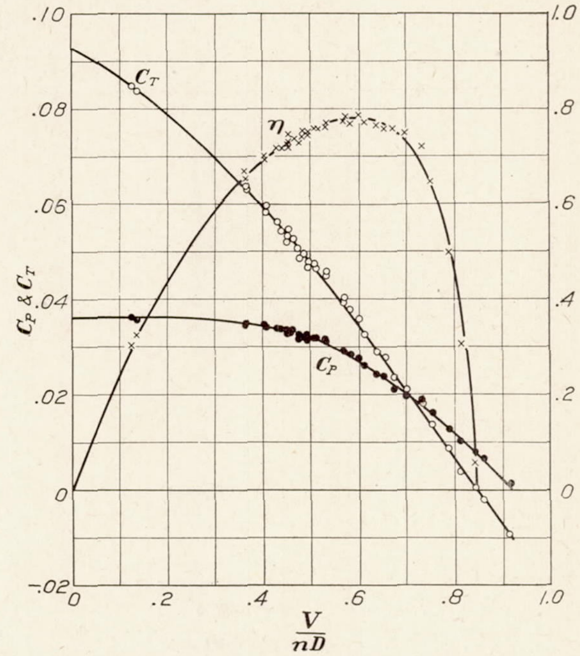


FIGURE 8.—Propeller No. 4412. Diameter 8 feet 11 inches

operating at the same value of C_S are fulfilling like requirements of power, velocity, and revolutions, and are, therefore, on a fair basis for comparison.

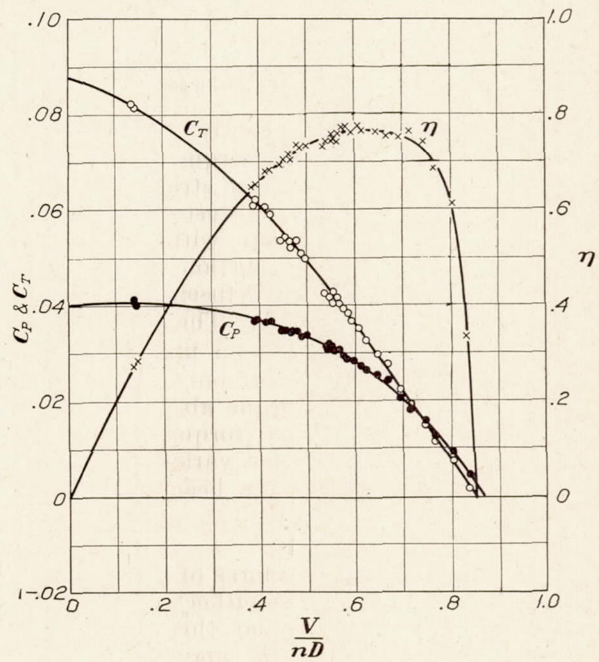


FIGURE 9.—Reed-R propeller. Diameter 9 feet

DISCUSSION

1. Comparison of the detachable blade forms.

(a) Propellers Nos. 4412 and 3790 had the same maximum efficiency, and very

nearly the same efficiency throughout the entire working range. The slight difference which does occur can be explained by the slightly lower zero thrust pitch of No. 3790. No. 4412,

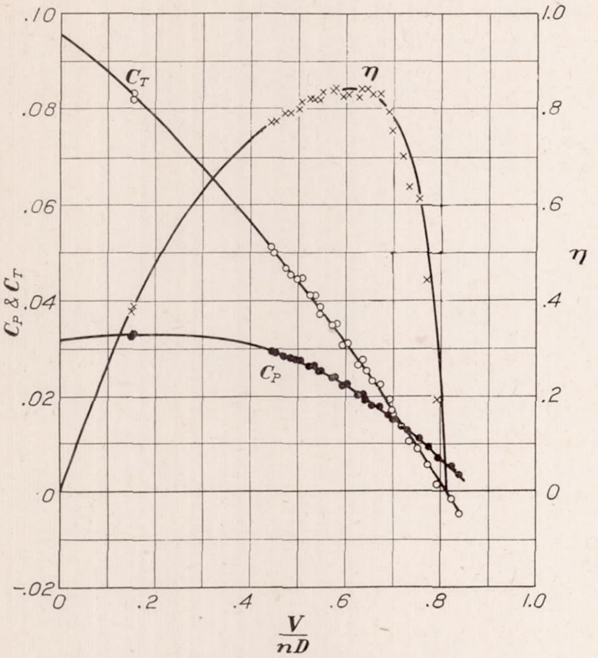


FIGURE 10.—Propeller No. 4102. Diameter 10 feet 5 inches

with its wider and thicker blades, absorbed about 13 per cent more power at maximum efficiency.

(b) The maximum efficiency of No. 3603 was found to be about 1 per cent greater

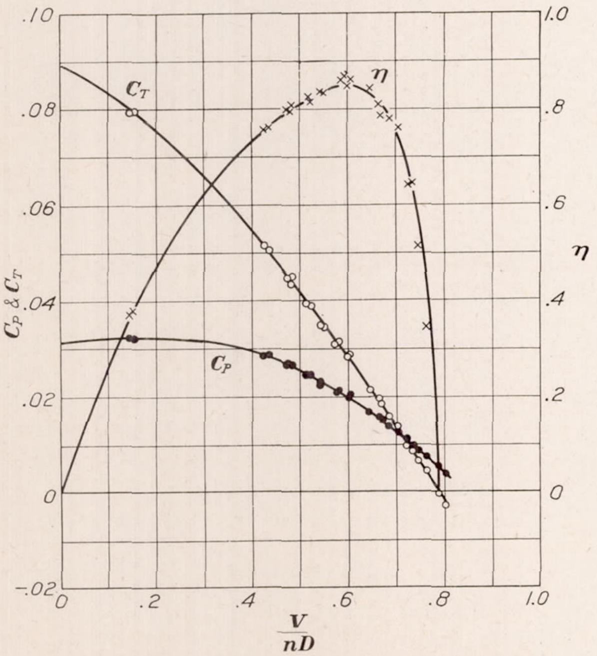


FIGURE 11.—Propeller No. 3603. Diameter 10 feet 5 inches

than that of No. 4102, and No. 4102 absorbed about 15 per cent more power at maximum efficiency.

(c) Although no direct comparison can be made between No. 3603 and No. 3790 (wide and narrow tips, same thickness, but wider tip having lower section thickness ratio), an indirect comparison is possible because propellers Nos. 4102 and 4412 are geometrically similar. According to the indirect comparison, No. 3603 and No. 3790 have about the

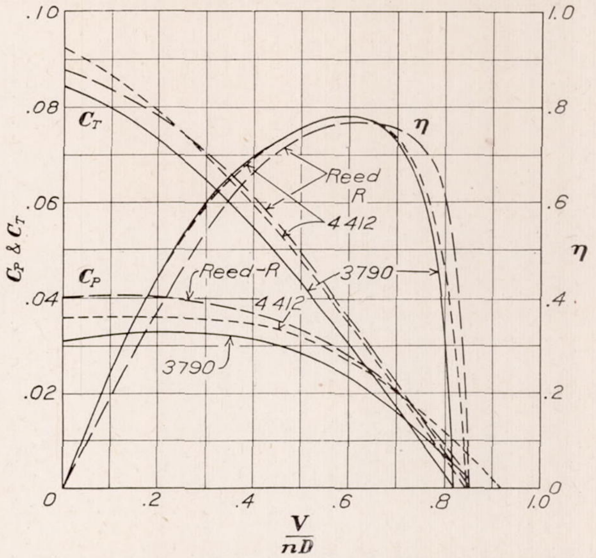


FIGURE 12.—Comparative curves of thrust coefficients, power coefficients, and efficiencies

same power coefficients at maximum efficiency, and the maximum efficiency of No. 3603, which has the wider tips and relatively thinner tip sections, is about 1 per cent higher than that of No. 3790.

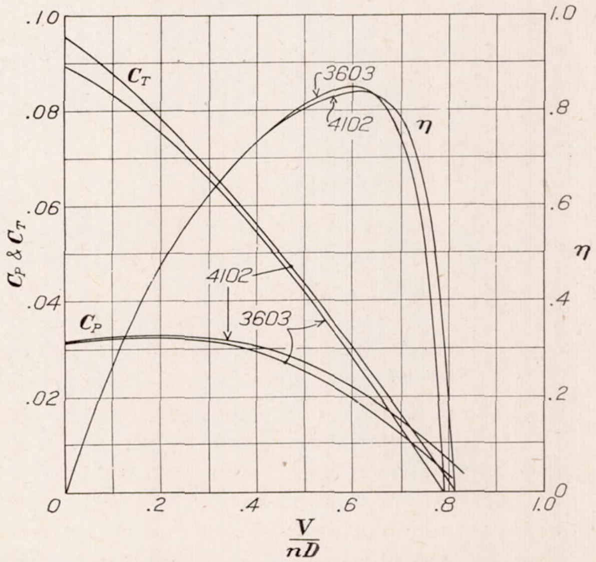


FIGURE 13.—Comparative curves of thrust coefficients, power coefficients, and efficiencies

2. Comparison of the Reed–R type propeller with the other forms.

(a) The Reed–R type propeller, which differed from No. 4412 mainly in that it had modified Clark Y airfoil sections and

approximately uniform pitch distribution, had a maximum efficiency about 2 per cent less than that of Nos. 4412 and 3790, and about 3 per cent less than that of No. 3603 under the same conditions.

(*b*) The Reed–R propeller absorbs slightly more power than No. 4412 at maximum efficiency, and its maximum efficiency occurs at a slightly higher value of *Cs*, so that the pitch is aerodynamically slightly greater than that of No. 4412 or the other propellers. If the pitches were aerodynamically the same, the maximum efficiency of the R type would be relatively still lower, but its efficiency at the lower rates of advance would be slightly higher than at present.

(*c*) The airfoil sections of the Reed–R propeller should, judging by wind-tunnel airfoil tests, be at least as efficient as those of the other propellers. The lower efficiency must, therefore, be attributed mainly to the uniform pitch distribution, with which the blade sections near the body work at inefficiently high angles of attack.

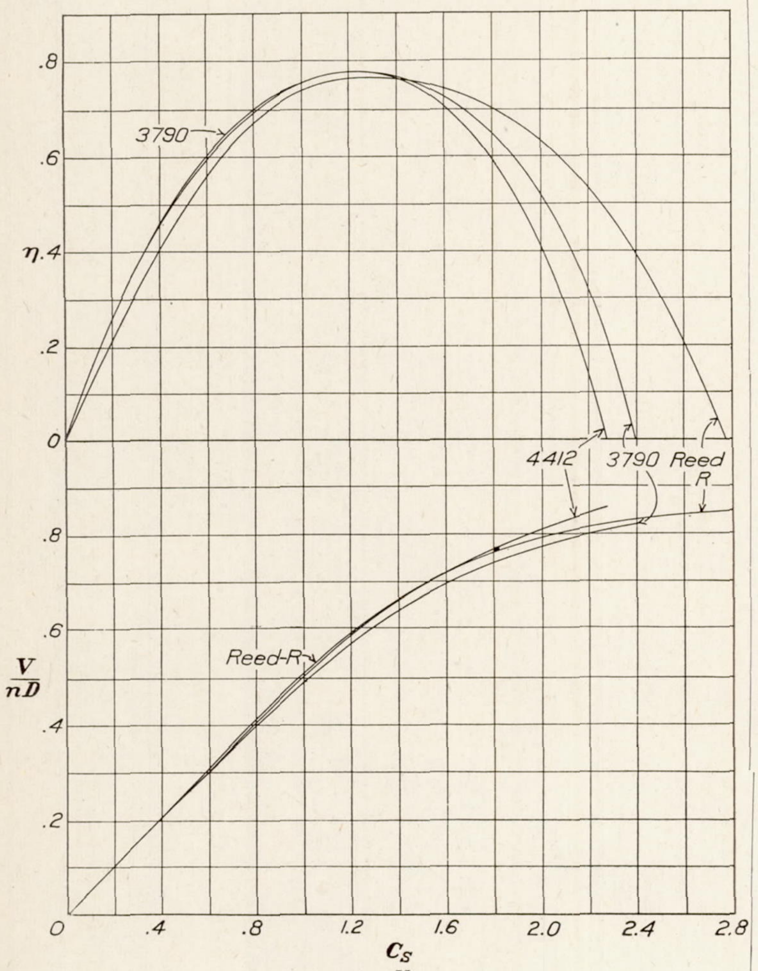


FIGURE 14.—$\frac{V}{nD}$ and η vs. Cs

CONCLUSIONS

1. The blade form having airfoil sections of the lowest thickness ratio (No. 3603) had the highest maximum efficiency.

2. Differences in efficiency between the various blade forms were small.

3. The propellers having the pitch reduced toward the hub had higher efficiencies than the one uniform pitch propeller, when operating on the particular engine and body used in the tests.

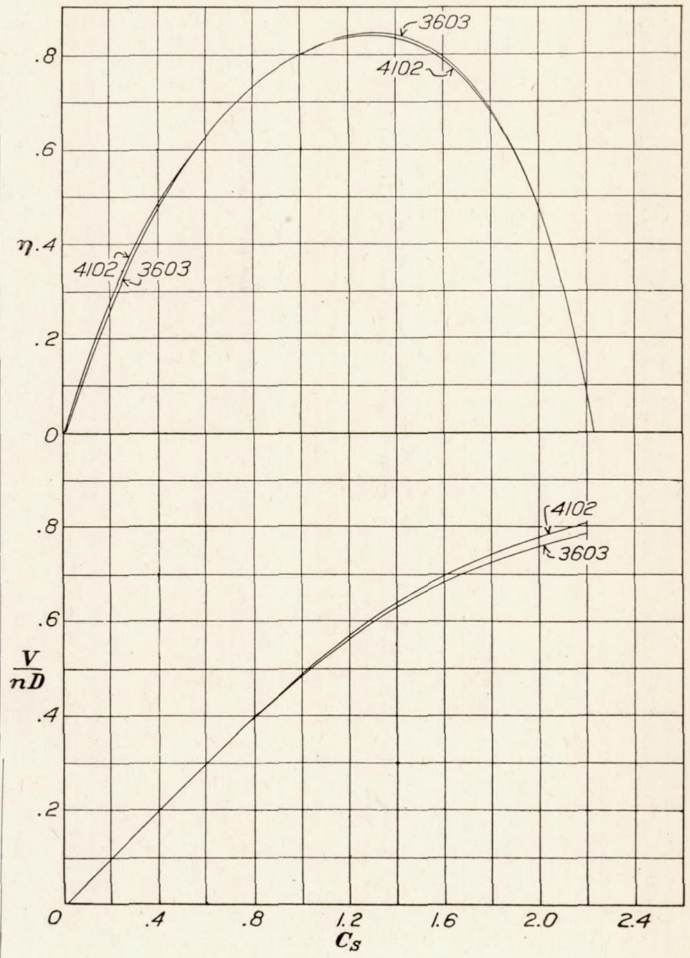


FIGURE 15.—$\frac{V}{nD}$ and η vs. Cs

LANGLEY MEMORIAL AERONAUTICAL LABORATORY,
NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS,
LANGLEY FIELD, VA., *March 18, 1929*.

REFERENCES

1. Weick, Fred E.: Full Scale Tests on a Thin Metal Propeller at Various Tip Speeds. N. A. C. A. Technical Report No. 302, 1928.
2. Weick, Fred E. and Wood, Donald H.: The Twenty Foot Propeller Research Tunnel of the National Advisory Committee for Aeronautics. N. A. C. A. Technical Report No. 300, 1928.

TABLE NO. I

OBSERVED TEST DATA

Propeller No. 3790

Diameter, 8 feet 11 inches

ρ	V m. p. h.	N r. p. m.	Q lb. ft.	T lb.	C_T	C_P	$\frac{V}{nD}$	η
0. 002222	85. 8	1, 695	447	476	. 0425	0. 0281	0. 500	0. 755
. 002222	86. 3	1, 690	442	471	. 0423	. 0280	. 504	. 760
. 002222	89. 1	1, 700	438	459	. 0406	. 0273	. 517	. 769
. 002222	88. 8	1, 700	438	455	. 0403	. 0273	. 516	. 762
. 002218	91. 4	1, 700	435	444	. 0395	. 0274	. 530	. 765
. 002211	91. 7	1, 700	435	441	. 0394	. 0274	. 533	. 766
. 002207	104. 8	1, 750	404	378	. 0318	. 0240	. 591	. 783
. 002207	103. 6	1, 745	405	380	. 0322	. 0242	. 586	. 780
. 002207	102. 9	1, 700	367	338	. 0302	. 0231	. 596	. 780
. 002207	103. 4	1, 660	325	292	. 0274	. 0214	. 616	. 790
. 002207	102. 9	1, 595	291	252	. 0256	. 0208	. 636	. 783
. 002207	102. 9	1, 550	248	205	. 0220	. 0188	. 655	. 766
. 002207	102. 9	1, 490	217	165	. 0192	. 0178	. 681	. 735
. 002207	102. 5	1, 445	181	135	. 0167	. 0158	. 700	. 740
. 002207	102. 3	1, 390	143	98	. 0131	. 0134	. 726	. 706
. 002207	102. 4	1, 360	119	72	. 0100	. 0117	. 744	. 638
. 002201	102. 1	1, 280	80	36	. 0057	. 0089	. 788	. 504
. 002201	101. 5	1, 225	41	1	. 0001	. 0049	. 819	. 028
. 002201	101. 5	1, 165	8	−36	−. 0068	. 0010	. 861	----------
. 002204	93. 2	1, 695	412	408	. 0367	. 0261	. 544	. 765
. 002204	93. 4	1, 690	412	405	. 0367	. 0263	. 545	. 760
. 002209	81. 8	1, 675	446	486	. 0448	. 0289	. 482	. 748
. 002209	82. 0	1, 660	442	480	. 0450	. 0292	. 488	. 753
. 002209	77. 8	1, 640	447	502	. 0482	. 0302	. 469	. 749
. 002209	77. 8	1, 650	447	495	. 0468	. 0300	. 465	. 725
. 002209	74. 2	1, 610	422	479	. 0476	. 0296	. 455	. 731
. 002209	74. 8	1, 600	420	471	. 0475	. 0299	. 461	. 732
. 002213	70. 6	1, 620	444	517	. 0508	. 0306	. 430	. 715
. 002213	70. 7	1, 630	442	514	. 0496	. 0302	. 429	. 705
. 002216	59. 4	1, 610	462	597	. 0595	. 0324	. 364	. 669
. 002216	62. 1	1, 610	460	578	. 0575	. 0322	. 380	. 679
. 002216	65. 4	1, 660	480	593	. 0555	. 0316	. 389	. 683
. 002216	64. 7	1, 650	477	595	. 0563	. 0318	. 388	. 687
. 002220	20. 3	1, 580	449	763	. 0787	. 0326	. 127	. 306
. 002220	20. 9	1, 580	449	748	. 0770	. 0326	. 130	. 309

TABLE NO. I—Continued

Propeller No. 4412

Diameter, 8 feet 11 inches

ρ	V m. p. h.	N r. p. m.	Q lb. ft.	T lb.	C_T	C_P	$\frac{V}{nD}$	η
0. 002288	82. 1	1, 750	579	646	0. 0525	0. 0332	0. 464	0. 734
. 002280	82. 5	1, 710	542	591	. 0505	. 0327	. 476	. 735
. 002280	82. 8	1, 705	524	562	. 0484	. 0318	. 479	. 729
. 002272	82. 9	1, 690	519	555	. 0488	. 0322	. 484	. 734
. 002272	83. 8	1, 680	513	551	. 0490	. 0322	. 492	. 749
. 002272	82. 8	1, 685	516	556	. 0494	. 0322	. 485	. 744
. 002272	83. 5	1, 690	516	559	. 0492	. 0320	. 488	. 750
. 002269	88. 3	1, 750	550	582	. 0476	. 0318	. 498	. 746
. 002269	88. 0	1, 750	545	572	. 0469	. 0314	. 496	. 740
. 002269	90. 8	1, 765	561	586	. 0474	. 0319	. 509	. 755
. 002262	91. 1	1, 760	555	575	. 0468	. 0317	. 511	. 755
. 002259	94. 2	1, 750	547	558	. 0460	. 0318	. 531	. 770
. 002259	94. 2	1, 750	541	554	. 0452	. 0315	. 531	. 763
. 002256	104. 4	1, 810	529	511	. 0394	. 0290	. 570	. 775
. 002256	104. 1	1, 805	528	514	. 0398	. 0290	. 570	. 782
. 002256	103. 5	1, 750	485	457	. 0378	. 0282	. 584	. 769
. 002256	103. 5	1, 700	444	409	. 0358	. 0274	. 601	. 785
. 002256	103. 1	1, 650	396	350	. 0324	. 0260	. 616	. 769
. 002256	103. 0	1, 595	344	291	. 0289	. 0241	. 639	. 765
. 002248	102. 7	1, 550	318	261	. 0274	. 0236	. 653	. 758
. 002248	102. 4	1, 500	265	210	. 0236	. 0210	. 675	. 758
. 002248	103. 1	1, 455	233	175	. 0210	. 0196	. 700	. 748
. 002248	103. 5	1, 390	200	138	. 0181	. 0185	. 735	. 720
. 002248	103. 4	1, 355	165	100	. 0138	. 0160	. 754	. 650
. 002248	103. 1	1, 290	119	56	. 0085	. 0127	. 790	. 495
. 002248	102. 4	1, 240	87	23	. 0038	. 0101	. 815	. 306
. 002248	102. 8	1, 200	63	3	. 0005	. 0078	. 845	. 057
. 002248	102. 5	1, 100	7	−47	−. 0098	. 0010	. 920	---------
. 002248	102. 5	1, 175	49	−11	−. 0020	0063	. 861	---------
. 002258	80. 6	1, 760	579	666	. 0545	. 0332	. 453	. 744
. 002249	81. 5	1, 750	566	637	. 0525	. 0330	. 459	. 730
. 002252	78. 9	1, 705	538	599	. 0521	. 0330	. 456	. 720
. 002252	78. 9	1, 705	536	601	. 0524	. 0328	. 456	. 729
. 002252	74. 3	1, 705	549	645	. 0561	. 0336	. 430	. 719
. 002252	75. 7	1, 700	542	621	. 0545	. 0334	. 440	. 719
. 002255	68. 5	1, 675	540	655	. 0591	. 0344	. 404	. 695
. 002255	68. 2	1, 670	535	649	. 0589	. 0342	. 403	. 694
. 002255	61. 2	1, 660	541	688	. 0632	. 0350	. 364	. 656
. 002255	62. 8	1, 645	533	666	. 0624	. 0350	. 377	. 670
. 002264	20. 8	1, 600	519	859	. 0845	. 0360	. 128	. 302
. 002264	22. 2	1, 590	511	838	. 0834	. 0358	. 138	. 321

TABLE NO. I—Continued

Reed-R Type Propeller

Diameter, 9 feet

ρ	V m. p. h.	N r. p. m.	Q lb. ft.	T lb.	C_T	C_P	$\frac{V}{nD}$	η
0. 002242	85. 3	1, 540	429	409	0. 0422	0. 0308	0. 541	0. 741
. 002242	84. 3	1, 530	427	407	. 0425	. 0311	. 539	. 736
. 002242	87. 7	1, 540	428	400	. 0413	. 0308	. 554	. 742
. 002242	88. 2	1, 540	428	397	. 0410	. 0308	. 559	. 745
. 002242	89. 2	1, 540	428	400	. 0413	. 0308	. 566	. 760
. 002242	89. 2	1, 550	432	399	. 0405	. 0307	. 562	. 741
. 002238	92. 9	1, 650	497	476	. 0429	. 0314	. 550	. 750
. 002238	92. 9	1, 640	493	472	. 0430	. 0314	. 554	. 758
. 002229	104. 3	1, 765	529	497	. 0393	. 0292	. 577	. 777
. 002229	104. 5	1, 760	523	485	. 0386	. 0289	. 580	. 775
. 002229	103. 6	1, 705	483	434	. 0368	. 0286	. 596	. 767
. 002229	103. 2	1, 660	440	389	. 0350	. 0275	. 609	. 775
. 002229	102. 9	1, 620	403	347	. 0325	. 0263	. 620	. 765
. 002229	103. 2	1, 560	355	294	. 0298	. 0251	. 646	. 767
. 002229	102. 5	1, 500	315	250	. 0274	. 0242	. 668	. 756
. 002229	102. 6	1, 450	250	190	. 0222	. 0204	. 691	. 754
. 002229	102. 4	1, 400	206	153	. 0192	. 0180	. 715	. 764
. 002229	102. 5	1, 350	167	116	. 0156	. 0157	. 742	. 740
. 002229	102. 1	1, 300	125	79	. 0115	. 0128	. 768	. 688
. 002229	102. 0	1, 240	86	46	. 0073	. 0096	. 804	. 613
. 002229	101. 6	1, 190	40	11	. 0019	. 0048	. 835	. 330
. 002229	83. 1	1, 665	545	571	. 0508	. 0338	. 489	. 734
. 002237	83. 8	1, 660	538	557	. 0498	. 0334	. 494	. 736
. 002230	78. 2	1, 640	537	570	. 0521	. 0343	. 466	. 708
. 002230	78. 9	1, 610	525	560	. 0533	. 0348	. 478	. 731
. 002230	74. 8	1, 590	511	554	. 0539	. 0347	. 460	. 715
. 002230	74. 8	1, 585	508	542	. 0532	. 0347	. 461	. 707
. 002234	68. 5	1, 500	454	496	. 0543	. 0347	. 446	. 696
. 002234	69. 1	1, 500	454	493	. 0540	. 0347	. 451	. 701
. 002234	64. 4	1, 530	502	578	. 0607	. 0368	. 412	. 680
. 002234	66. 0	1, 530	497	562	. 0590	. 0364	. 422	. 684
. 002236	60. 2	1, 500	485	568	. 0620	. 0370	. 392	. 657
. 002236	60. 0	1, 505	483	565	. 0613	. 0366	. 389	. 651
. 002242	19. 6	1, 405	472	662	. 0820	. 0410	. 136	. 274
. 002242	20. 2	1, 405	469	657	. 0813	. 0406	. 140	. 281

TABLE NO. I—Continued

Propeller No. 4102

Diameter, 10 feet 5 inches

ρ	V m. p. h.	N r. p. m.	Q lb. ft.	T lb.	C_T	C_P	$\frac{V}{nD}$	η
0.002288	83.0	1,115	316	252	0.0270	0.0205	0.629	0.828
.002288	83.6	1,115	316	253	.0272	.0205	.634	.841
.002288	83.4	1,090	285	224	.0252	.0193	.645	.841
.002288	83.2	1,070	261	199	.0232	.0183	.657	.831
.002288	82.8	1,040	243	182	.0224	.0181	.673	.831
.002280	83.0	1,015	211	147	.0191	.0165	.691	.799
.002280	82.5	995	186	121	.0164	.0151	.700	.757
.002280	82.2	965	162	96	.0138	.0141	.720	.705
.002280	82.0	940	134	70	.0106	.0122	.736	.640
.002280	81.8	915	115	56	.0089	.0110	.755	.614
.002280	81.6	890	93	32	.0054	.0094	.775	.443
.002280	81.3	865	66	10	.0017	.0071	.794	.199
.002280	81.3	835	48	−6	−.0011	.0055	.824	---
.002280	81.0	815	31	−23	−.0046	.0037	.840	---
.002280	78.4	1,110	339	284	.0309	.0222	.596	.830
.002280	79.2	1,115	344	288	.0310	.0224	.601	.831
.002283	75.1	1,100	361	317	.0350	.0240	.576	.840
.002283	75.4	1,100	360	317	.0350	.0240	.579	.844
.002283	71.6	1,100	378	344	.0381	.0252	.550	.831
.002283	71.5	1,100	378	342	.0378	.0252	.549	.824
.002283	68.6	1,100	397	373	.0413	.0264	.527	.825
.002283	69.4	1,100	398	371	.0410	.0266	.533	.821
.002286	65.2	1,100	416	404	.0446	.0277	.501	.806
.002286	65.6	1,100	416	404	.0446	.0277	.505	.814
.002286	62.0	1,105	425	430	.0470	.0281	.474	.792
.002286	63.0	1,100	423	416	.0459	.0281	.484	.790
.002286	58.0	1,100	441	466	.0515	.0296	.446	.776
.002286	58.2	1,090	427	443	.0499	.0290	.451	.776
.002286	19.6	1,100	491	749	.0828	.0327	.150	.382
.002286	19.9	1,100	495	750	.0830	.0330	.153	.385

TABLE NO. I—Continued

Propeller No. 3603

Diameter, 10 feet 5 inches

ρ	V m. p. h.	N r. p. m.	Q lb. ft.	T lb.	C_T	C_P	$\frac{V}{nD}$	η
0.002323	84.0	1,100	253	199	0.0216	0.0165	0.645	0.841
.002323	84.4	1,073	230	167	.0191	.0158	.665	.805
.002323	83.4	1,052	216	154	.0183	.0155	.669	.788
.002323	83.4	1,023	184	126	.0158	.0139	.688	.782
.002323	83.6	1,000	160	104	.0136	.0127	.706	.760
.002323	83.3	970	133	71	.0099	.0112	.725	.640
.002323	83.4	940	100	41	.0061	.0089	.749	.512
.002323	83.6	965	115	61	.0086	.0097	.733	.646
.002323	83.4	920	81	22	.0034	.0075	.765	.345
.002323	83.2	890	50	−2	−.0003	.0050	.790	---
.002323	83.1	875	38	−15	−.0025	.0039	.804	---
.002318	78.6	1,105	309	264	.0286	.0202	.601	.850
.002318	79.1	1,108	310	265	.0286	.0201	.604	.859
.002318	75.8	1,108	324	290	.0312	.0210	.579	.860
.002318	75.7	1,102	324	290	.0315	.0212	.580	.862
.002309	71.1	1,100	341	313	.0344	.0225	.546	.835
.002309	71.2	1,100	341	315	.0344	.0225	.547	.836
.002312	67.3	1,100	369	357	.0390	.0244	.516	.825
.002312	67.9	1,100	369	351	.0384	.0244	.521	.820
.002312	64.1	1,105	406	403	.0435	.0266	.491	.804
.002312	64.6	1,110	409	405	.0435	.0265	.491	.805
.002312	62.0	1,105	409	415	.0449	.0267	.474	.796
.002312	62.4	1,100	409	410	.0449	.0270	.479	.796
.002312	57.7	1,125	455	481	.0504	.0287	.434	.761
.002312	57.0	1,125	455	490	.0512	.0287	.428	.764
.002321	19.7	1,100	488	727	.0791	.0320	.151	.374
.002321	19.5	1,100	489	728	.0792	.0320	.149	.370

TABLE NO. II

FINAL ADJUSTED COEFFICIENTS

Propeller No. 3790

Diameter, 8 feet 11 inches

$\frac{V}{nD}$	C_T	C_P	η	C_S
0.10	0.0800	0.0323	0.248	0.198
.15	.0770	.0329	.351	.296
.20	.0734	.0330	.445	.395
.25	.0695	.0330	.526	.494
.30	.0650	.0328	.595	.594
.35	.0601	.0322	.654	.696
.40	.0549	.0314	.699	.798
.45	.0489	.0302	.729	.905
.50	.0429	.0285	.752	1.019
.55	.0367	.0262	.770	1.140
.60	.0301	.0232	.779	1.272
.65	.0235	.0200	.764	1.421
.70	.0167	.0160	.729	1.599
.75	.0100	.0118	.635	1.821
.80	.0031	.0069	.360	2.170

TABLE NO. II—Continued

Propeller No. 4412

Diameter, 8 feet 11 inches

$\frac{V}{nD}$	C_T	C_P	η	C_S
0.10	0.0864	0.0360	0.240	0.194
.15	.0829	.0360	.346	.292
.20	.0789	.0360	.438	.389
.25	.0746	.0360	.518	.486
.30	.0698	.0359	.582	.584
.35	.0649	.0352	.645	.682
.40	.0591	.0342	.690	.785
.45	.0539	.0335	.723	.886
.50	.0478	.0318	.751	.996
.55	.0412	.0294	.770	1.112
.60	.0360	.0270	.778	1.232
.65	.0279	.0236	.770	1.376
.70	.0210	.0199	.739	1.531
.75	.0140	.0160	.656	1.711
.80	.0070	.0119	.471	1.941

TABLE NO. II—Continued

Reed–R Type Propeller

Diameter, 9 feet

$\frac{V}{nD}$	C_T	C_P	η	C_S
0.10	0.0837	0.0408	0.205	0.189
.15	.0810	.0405	.300	.284
.20	.0779	.0402	.387	.380
.25	.0742	.0400	.464	.474
.30	.0702	.0391	.539	.573
.35	.0659	.0380	.606	.674
.40	.0609	.0369	.660	.774
.45	.0552	.0353	.705	.879
.50	.0491	.0333	.737	.985
.55	.0425	.0310	.755	1.102
.60	.0359	.0281	.765	1.225
.65	.0290	.0247	.763	1.361
.70	.0216	.0201	.751	1.530
.75	.0150	.0156	.720	1.725
.80	.0078	.0099	.630	.201

TABLE NO. II—Continued

Propeller No. 4102

Diameter, 10 feet 5 inches

$\frac{V}{nD}$	C_T	C_P	η	C_S
0.10	0.0880	0.0328	0.268	0.198
.15	.0833	.0330	.378	.296
.20	.0788	.0329	.479	.396
.25	.0738	.0328	.562	.495
.30	.0680	.0322	.633	.596
.35	.0625	.0319	.686	.697
.40	.0564	.0308	.732	.801
.45	.0500	.0292	.771	.912
.50	.0442	.0274	.807	1.025
.55	.0380	.0252	.830	1.148
.60	.0314	.0224	.840	1.281
.65	.0246	.0192	.832	1.432
.70	.0170	.0152	.781	1.616
.75	.0100	.0115	.650	1.832

TABLE NO. II—Continued

Propeller No. 3603

Diameter, 10 feet 5 inches

$\frac{V}{nD}$	C_T	C_P	η	C_S
0.10	0.0832	0.0321	0.259	0.198
.15	.0796	.0322	.371	.298
.20	.0755	.0322	.469	.398
.25	.0709	.0320	.554	.498
.30	.0659	.0316	.625	.599
.35	.0604	.0309	.684	.701
.40	.0543	.0296	.733	.809
.45	.0482	.0279	.778	.920
.50	.0415	.0256	.810	1.041
.55	.0349	.0229	.838	1.170
.60	.0282	.0199	.850	1.311
.65	.0211	.0165	.830	1.477
.70	.0139	.0128	.760	1.675
.75	.0062	.0086	.541	1.941

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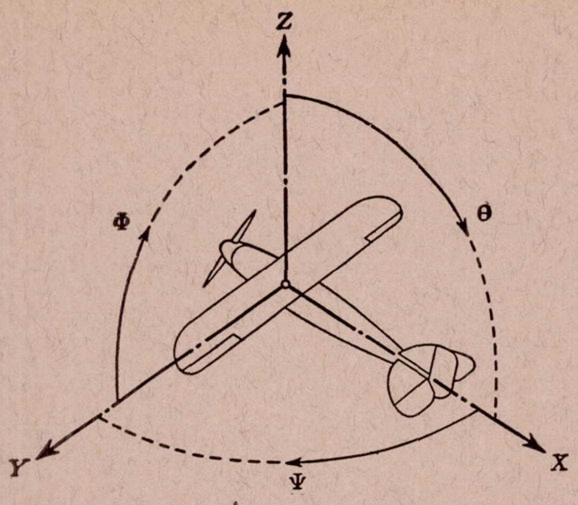

Positive directions of axes and angles (forces and moments) are shown by arrows

Axis		Force (parallel to axis) symbol	Moment about axis			Angle		Velocities	
Designation	Symbol		Designation	Symbol	Positive direction	Designation	Symbol	Linear (component along axis)	Angular
Longitudinal	X	X	rolling	L	$Y \longrightarrow Z$	roll	Φ	u	p
Lateral	Y	Y	pitching	M	$Z \longrightarrow X$	pitch	Θ	v	q
Normal	Z	Z	yawing	N	$X \longrightarrow Y$	yaw	Ψ	w	r

Absolute coefficients of moment

$$C_L = \frac{L}{qbS} \qquad C_M = \frac{M}{qcS} \qquad C_N = \frac{N}{qfS}$$

Angle of set of control surface (relative to neutral position), δ. (Indicate surface by proper subscript.)

4. PROPELLER SYMBOLS

D, Diameter.
p_e, Effective pitch.
p_g, Mean geometric pitch.
p_s, Standard pitch.
p_t, Zero thrust.
p_q, Zero torque.
p/D, Pitch ratio.
V', Inflow velocity.
V_s, Slip stream velocity.

T, Thrust.
Q, Torque.
P, Power.
(If "coefficients" are introduced all units used must be consistent.)
η, Efficiency $= T\ V/P$.
n, Revolutions per sec., r. p. s.
N, Revolutions per minute, r. p. m.
Φ, Effective helix angle $= \tan^{-1}\left(\frac{V}{2\pi rn}\right)$

5. NUMERICAL RELATIONS

1 hp = 76.04 kg/m/s = 550 lb./ft./sec.
1 kg/m/s = 0.01315 hp
1 mi./hr. = 0.44704 m/s
1 m/s = 2.23693 mi./hr.

1 lb. = 0.4535924277 kg
1 kg = 2.2046224 lb.
1 mi. = 1609.35 m = 5280 ft.
1 m = 3.2808333 ft.